Histoacryl glue in meniscal repairs (a biomechanical study)

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Abstract The purpose of this study was to investigate the biomechanical efficacy of Histoacryl (cyanoacrylate, N-asetil 2 butyl sistein) in meniscal tear repair. In our study, the primary stability of three different repair techniques in delaying the formation of a gap of 2 mm was investigated. A meniscal tear was repaired with two vertical sutures and Histoacryl in the first group; it was repaired only with Histoacryl in the second group, and with only two vertical sutures in the third group. Menisci were then placed in a tensile loading machine, and the primary stability of the repair zones was measured until a displacement of 2 mm occurred. Biomechanical force was significantly ($P<0.05$) high (112.0 ± 17.20 N) in all groups when vertical suture and Histoacryl glue were used together during displacements of 0.5, 1.0, 1.5 and 2.0 mm. We believe that Histoacryl is superior to vertical sutures regarding gap delaying. It potentiates the effect of vertical suture strength, permits early motion and thus merits an in vivo study.

Résumé Etudier l'effet biomécanique de la colle histoacryle (Cyanoacrylate, N-asetil 2 butyl sistein) dans la réparation méniscale. Lors de cette première étude, nous avons utilisé trois techniques différentes de réparation d'une lésion méniscale de 2 mm. Cette lésion a été réparée soit par l'utilisation d'une suture et de l'histoacryle dans le premier groupe, avec de l'histoacryle seule dans le deuxième groupe et enfin avec une suture isolée dans le troisième groupe. Le ménisque a ensuite été placé en tension avec mensuration des forces nécessaires pour avoir une déchirure de 2 mm de la suture. Les forces à mettre en jeu sont significativement hautes (112.0 ± 17.20 N) dans les groupes où a été utilisée la glue histoacryle avec ou sans suture. Nous pensons que l'histoacryle donne un résultat bien supérieur à la suture isolée. Il renforce cette suture lorsque l'histoacryle et la suture sont utilisés de façon concomitante.

Introduction

The contemporary treatment method for peripheral longitudinal meniscal tears in young patients is repair, since the result of excision is unsatisfactory [4]. The disadvantages of the current repair techniques and materials include neurovascular complications, difficulty in performing anatomical repair, low primary stability, breakage, migration and slippage [4]. The primary stability of the repair technique is very important to maintain apposition of the tear site during the healing period and to expedite postoperative rehabilitation, early motion and weight bearing [4, 14, 19]. The vertical mattress suture technique is currently thought to have the highest primary stability [4, 7, 12].

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Fig. 1 Gap size measurement with a digital caliper during tensile loading in group S+H

Histoacryl, a member of the cyanoacrylate family, is a resorbable polymeric a powerful adhesive for tissues of high protein content like skin and tendon. It is not toxic, has a minimal inflammatory effect and does not interrupt tissue healing [1, 3, 20–23]. It is used clinically and experimentally as an embolic and haemostatic agent in vascular surgery, for treatment of retinal tears and corneal ulcers in ophthalmology, for graft surgery, tendon repairs, bone fixation in plastic and reconstructive surgery and osteochondral fracture fixation in orthopaedic surgery [1, 3, 17, 21, 24].

Although several studies comparing the primary stability and strength of the different suture techniques exist, none compares the vertical mattress suture, known to be the strongest, with Histoacryl with respect to the delay of gap formation. In our study, we investigated the primary stability of Histoacryl tissue adhesive in meniscal tears, which we hoped would decrease the failure risk by delaying gap formation between tear sites throughout the healing period, and thus achieve better healing and early rehabilitation.

Fig. 2 Gap size measurement with a digital caliper during tensile loading in group H

Fig. 3 Gap formation is observed with initiation of traction in group S

Materials and methods

Twenty-one bovine medial menisci were used in this study. The menisci were kept at -20°C in a deep freezer. They were taken out of the freezer and held in saline solution for 8 h before the procedure. They were put in saline before and after each procedure to simulate the intra-articular moist environment of the menisci. Three groups of seven menisci were tested.

In the first group (group S+H), two vertical sutures and Histoacryl were used (Fig. 1). In the second group (group H), only Histoacryl was applied (Fig. 2), and finally in the third group (group S), only two vertical sutures were used (Fig. 3).

Peripheral longitudinal tears of 25 mm in length localised 3–4 mm central to the rim were created in all specimens using a no. 11 blade. For the repair of menisci in group S+H, two vertical sutures 5–6 mm apart with no. 2/0 prolene and Histoacryl (2-butyl cyanoacrylate-BRAUN AESCULAP 1×1.5 cc Histoacryl tissue adhesive produced from enbucrilate) were used. For Histoacryl to adhere effectively, the surfaces had to be wet and held in compression for 1–2 min [3, 22]. Thus, the menisci were held in saline solution during the setting process. After the application of 0.1 cc Histoacryl and compression to the tear site for 1 min, vertical sutures were tied.

We applied tensile load forces 1 h after the repair, as described in the study by Trail [22] and Chesky [10]. The menisci in group H were glued only with the same amount of Histoacryl. The menisci in group S were sutured by using the vertical mattress technique. Suturing processes were performed with a spinal needle.

The strength of the adhesive is directly proportional to the size of the contact areas [3]. Thus, we standardised the meniscal areas to be tested ($333.7 \pm 56.0 \text{ mm}^2$). After the application of Histoacryl to the 25 mm of the tear site, the remaining meniscal horns were excised in order to maintain this standardisation and to ensure that the repair

Table 1 Relation between tensile load and gap in all groups

Gap (mm)	Mean load (N) Group S+H	Mean load (N) Group H	Mean load (N) Group S
0.5	54.77±3.41	44.42±11.86	24.06±9.07
1.0	66.61±6.20	53.63±9.12	32.53±11.84
1.5	84.43±8.60	69.24±10.13	40.70±10.42
2.0	112.0±17.20	76.73±7.34	47.70±8.83

Shows mean load that resulted in various gap sizes at the repair site for each repair technique

N: Newton

device, not the meniscal tissue, provided the fixation's stability [13].

Using no. 5 ethibond, two traction sutures were applied on the concave and convex sides of menisci. The prepared materials were then placed in the traction device.

The tensile test was performed to record the load-gap curve. The meniscal specimens were tested using the biomaterial testing machine (MAY 03, USA). The tensile loading speed in all tests was 20 mm/min. Data were transferred to computers that translated to numerical signals by using a 16-bit A/D converter for off-line analysis. The sampling rate was chosen as 1,000 sample/s. During mounting and testing of the specimens, physiological saline was regularly applied to prevent the specimens from drying. Each specimen was subjected to a small initial preload of 10 N before the actual testing for a period of 1 min. Load-gap data were recorded using the BIOPAC MP 100 Acquisition System, Version 3.5.7 (Santa Barbara, Calif.). During loading, the gap of the repair site was measured with a digital caliper (Figs. 1 and 2). The forces required to cause displacements of 0.5, 1.0, 1.5 and 2.0 mm at each measurement site were recorded as an indicator of the strength of each of the four different gap displacements.

Fig. 4 Mean load-gap curve

In all specimens measurement of the gap formed was accomplished on the tear line parallel to the traction sutures.

Statistical analysis

Statistical analysis was performed by using SPSS v.10.0 software. After documenting normal distribution (Kalmogorov-Smirnov), data were expressed as the mean±SD. Statistical comparisons were made using the analysis of variance and Tukey tests with $P<0.05$ considered as significant.

Results

In our study a gap of 2 mm was considered to be the limit of failure. Pull out or breakage of traction and repair sutures was not observed.

Mean tensile load-gap values were greater than other groups in group S+H, in which vertical suture and Histoacryl were used together. Histoacryl used alone in group H had lower values than the suture and Histoacryl group S+H, and use of vertical sutures alone resulted in the lowest values (Table 1) (Fig. 4). Statistically, the difference was not significant between the S+H and H groups until the formation of a gap of 2 mm. Significant differences between these groups were found only when the gap was 2 mm ($P=0.001$). Statistically significant values were found between the S+H and S groups when the gap was greater than 0.5 mm ($P=0.000$), and between H and S groups when the gap was greater than 0.5 mm ($P=0.004$) (Table 2). The gap formation during the tensile load process started at the adherence site in group SH, and the sutures started to bear load only after the gap was formed by separation of the adhered edges (Fig. 5).

In group S an initial gap formation with a magnitude between 0.1–0.3 mm occurred (Fig. 3). This incident was not observed in the groups in which Histoacryl was used to adhere the edges.

Discussion

In our study, the SH and only H groups were stronger than the only S group in meniscal repair.

Repair of vertical and longitudinal meniscal tears in the red and red-white zones that are greater than 10 mm is currently recommended, especially for patients younger than 45 years [4].

It is reported that the presence of gap formation will affect meniscal repairs adversely as it does in tendon repairs [12]. We think that motion in the repair site damages the inflammatory fibrinous scaffold, which is formed by

Table 2 Values of *P* for tensile load

For	0.5 mm	1.0 mm	1.5 mm	2.0 mm
Group S+H to H:	0.163	0.087	0.052	0.001
Group S+H to S:	0.000	0.000	0.000	0.000
Group H to S:	0.004	0.005	0.001	0.003

Shows mean time that resulted in various displacements at the repair site for each repair technique

Group S+H: Histoacryl glue + vertical mattress sutures

Group H: Histoacryl glue

bleeding, and this slows healing. Thus, it is important to have minimum motion during the healing period. Classical suture techniques or techniques that use all inside materials cannot prevent motion completely [17]. Studies that observe the ability of meniscal repair techniques to prevent gap formation show that vertical mattress sutures are better [8]. However, elastic properties of suture materials and menisci lead to gap formation in the initial steps of tensile loading [17].

In order to tie the sutures on the capsule and protect the neurovascular structures, additional incisions are needed during inside-out and outside-in repair techniques [11]. Difficulty in achieving perpendicular sutures to the tear line, especially in tears of the posterior horn, is an important disadvantage of suturing techniques. Obliquely oriented sutures may lead to failure of the repair, and the meniscus may not heal [4].

Good clinical results are reported to be between 56.5–98.6% after arthroscopic repair [4, 6, 12, 14]. Posterior horn tears have the greatest clinical failure, with reported rates of 40–92% [4, 16]. However, the successful repair of a posterior horn tear is important because of its effect on

the stability and content of the mechanoreceptors [15]. Failure rates are related to a variety of factors like insufficient vascular supply, tissue instability, inappropriate patient selection, instability of the knee joint, the initial fixation strength of the repair technique, the amount of cyclical stress and the hydrolysis of repair materials [11]. The vertical mattress suture technique is known to have the greatest initial stability, and therefore it is superior in delaying gap formation [4, 7, 12]. To have a successful meniscal repair, another important point is to approximate tear sites closely and achieve an anatomical repair [2]. Revascularization, which is important for effective healing, occurs better when the tear sites are approximated closely [2, 7]. For this reason, the ability of the repair material to hold the tear sites in apposition during the initial period is very important. There is no doubt that for a wound to heal faster with minimum scar formation the tear sites must stay approximated as much as possible during the healing period. In current practice, knee motion and weight bearing are not allowed for 2–8 weeks after meniscal repair because of the inability of the repair materials to prevent the separation of tear sites and the disruption of the inflammatory fibrinous scaffold that is formed by bleeding from tear sites [4, 14, 19]. However, the ideal meniscal repair should allow early rehabilitation and weight bearing while maintaining primary stability that will not allow gap formation [5, 6, 8]. In our study, the initial gap was not observed in groups S+H and H; on the other hand, gap formation was observed at the beginning of traction in group S. In group S+H, Histoacryl was separated before the sutures during traction (Fig. 5). Group H was stronger than group S by as much as 10 N. Chunfeng Zhao et al. [25] showed that in tendon repairs running sutures could tolerate loading until the formation of a gap of 2 mm, and then core sutures such as Kessler were loaded. All these findings lead us to the conclusion that, like the running sutures used in tendon repair, Histoacryl prevented direct loading of vertical mattress sutures, thus inhibiting gap formation at the beginning of traction.

Menisci are loaded by both tensile and shearing forces during flexion and extension [4, 17, 19]. In our study we tested only the tensile strengths in vitro and showed that the primary stability in repairs with both vertical suture techniques and Histoacryl tissue adhesive were greater than they were in repairs with only the vertical suture technique at all lengths of gap formations, meaning that Histoacryl has a great additive effect on the primary stability of the repair site (Table 1). When it was used for tendon repair in addition to classical repairs, Histoacryl was shown to elevate the primary stability and pull apart strength by 30 to 40% [9, 18, 22]. In our study, we found that the tensile strength of group SH was 134% of group H when the gap was 2 mm (Table 1).

Fig. 5 Histoacryl glue separates before sutures in group S+H

In our study, we evaluated tensile load forces in gap formations of 0.5, 1.0 and 2.0 mm. The highest force values, in accordance with the literature [9, 17, 22], were found in group S+H when the gap was 2 mm.

The fact that the statistical analysis of tensile load-gap data of all groups demonstrated no significant difference between the S+H and the H group until formation of a gap of 2 mm led us to the conclusion that Histoacryl, even if used alone, was better than the vertical suture technique in delaying gap formation. The presence of significant statistical differences commencing after the initiation of the process in the S+H and S groups and beginning after the 0.5-mm gap formation in the H and S groups demonstrated a lack of gap delaying effect in the suturing techniques when used alone, which parallels the results in the literature (Fig. 3) (Table 2), [17, 25]. As far as we are aware, there is one in vitro meniscus study [17] in which Histoacryl use in addition to the suture material was found to be the strongest method, as was found in our study. Failure strength was directly correlated with suture size and the size of the adhered area [3, 6, 25]. Koukoubis et al. used 3/0 prolene in their study. They found superior results with the use of sutures only than the use of adhesive materials with respect to failure rates. Koukoubis et al. accepted suture rupture or pull out and tissue separation as load to failure. However, in our study, a gap of 2 mm was considered to be failure. For this reason, contrary to our results, only group H was inferior to group S due to plastic deformation of the sutures or tissue in their study. The adhered area in this study was 43.75 mm², whereas it was 333.7±56.0 mm² in ours. The better results in the adhesive only group compared to the vertical suture group in our study might be the result of a larger area of adherence.

As a result, classical vertical sutures alone cannot prevent gap formation in the repair site leading to failure. However, Histoacryl delays gap formation by providing better primary stability to the repair site when used with classical vertical sutures, and alone until the gap formation is 2 mm. These findings support our hypothesis that failures resulting from a lack of primary stability of meniscal repairs will decrease with the use of Histoacryl. Although Histoacryl may prevent gap formation, does it, or would it, impede the healing of one meniscal edge to the other because it is interposed between the two leaves of the tear? Although the addition of Histoacryl to a meniscal repair may give the repair a better initial load to failure strength, it may ultimately lead to increased failures if it interferes with healing. Prior to any in vivo application, the authors need to see if the interposition of Histoacryl impedes healing in a tissue-healing experiment. Thus, in vivo testing of Histoacryl usage is required prior to clinical application.

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